

GFDL Summer School 2012

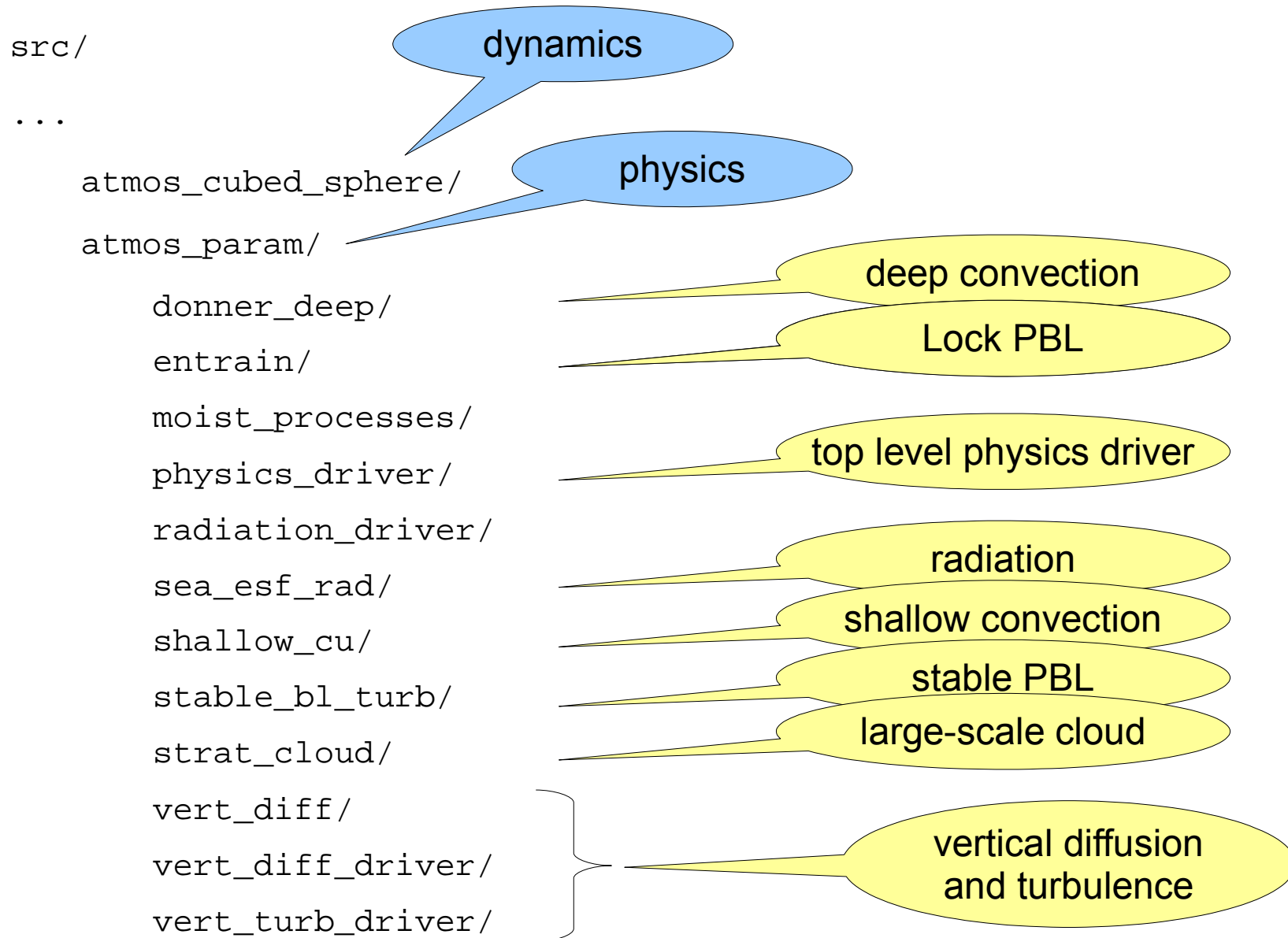
Boundary-layer and clouds in AM3

Chris Golaz

Overview

- Brief description of AM3 code structure
- PBL parameterization (planetary boundary layer)
- Large-scale clouds.

AM3 code structure



PBL parameterization

- **Purpose:** represent vertical transport of momentum, heat, scalars due to unresolved turbulence.
- Usually represented as vertical diffusion

$$\overline{w'\psi'} = -K \frac{\partial \bar{\psi}}{\partial z} \quad \leftarrow \text{vertical flux}$$

$$\frac{\partial \bar{\psi}}{\partial t} = -\frac{\partial}{\partial z} \overline{w'\psi'} = \frac{\partial}{\partial z} K \frac{\partial \bar{\psi}}{\partial z} \quad \leftarrow \text{tendency due to vertical flux}$$

- Need eddy diffusivity coefficients K

Vertical diffusion: implicit solution for atmosphere / soil

$$\frac{\partial}{\partial t} \bar{\psi} = \frac{\partial}{\partial z} K \frac{\partial \bar{\psi}}{\partial z}$$

Atmosphere

physics_driver_down
vert_diff_driver_down

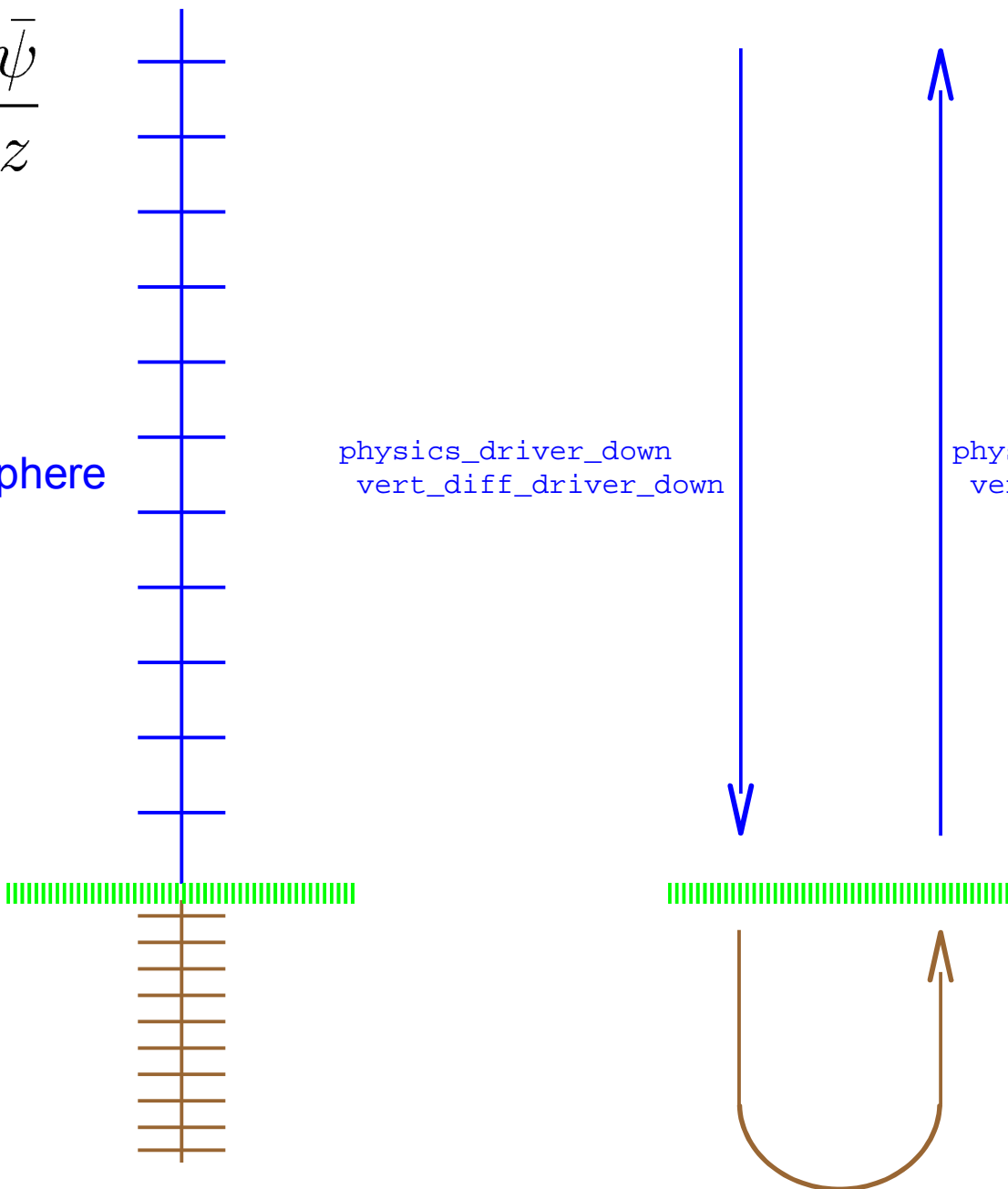
physics_driver_up
vert_diff_driver_up

Land

flux_exchange

Soil

land_model



Eddy diffusivity coefficients

In AM3, the eddy diffusivity coefficients, K , include contribution from

- stable scheme $K_{\text{stable}} = F(Ri)$
`src/atmos_param/stable_bl_turb/stable_bl_turb.F90`

- Lock boundary layer scheme $K_{\text{entr}} = \dots$
`src/atmos_param/entrain/entrain.F90`

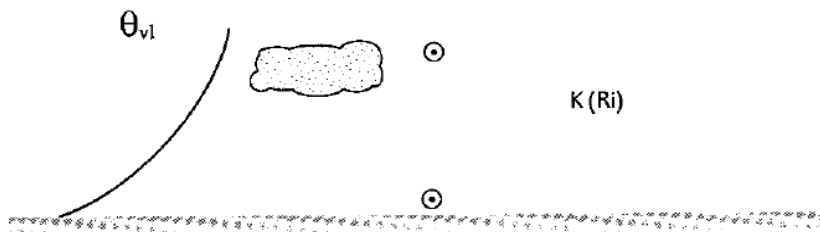
Combined coefficients

$$K = aK_{\text{entr}} + (1 - a)K_{\text{stable}} \quad a = \begin{cases} 1 : & \text{Lock active} \\ 0 : & \text{otherwise} \end{cases}$$

Lock et al. (2000): turbulent layers

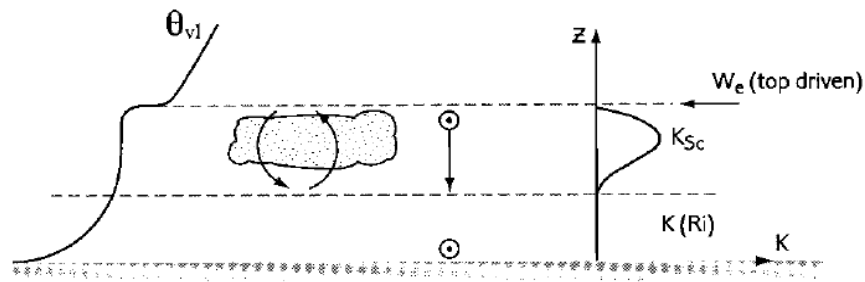
(a)

I. Stable boundary layer, possibly with non-turbulent cloud
(no cumulus, no decoupled Sc, stable surface layer)



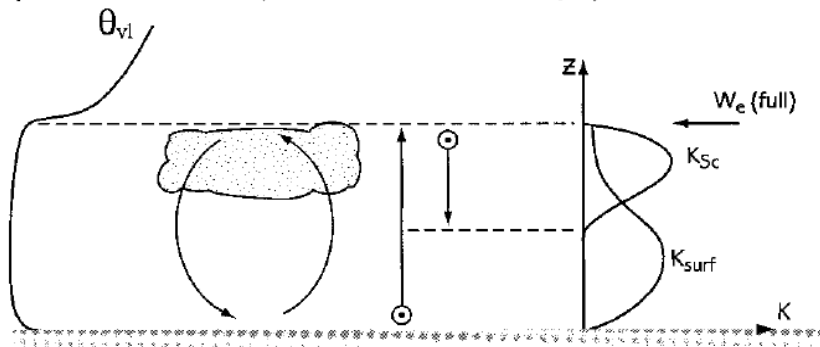
(b)

II. Stratocumulus over a stable surface layer
(no cumulus, decoupled Sc, stable surface layer)



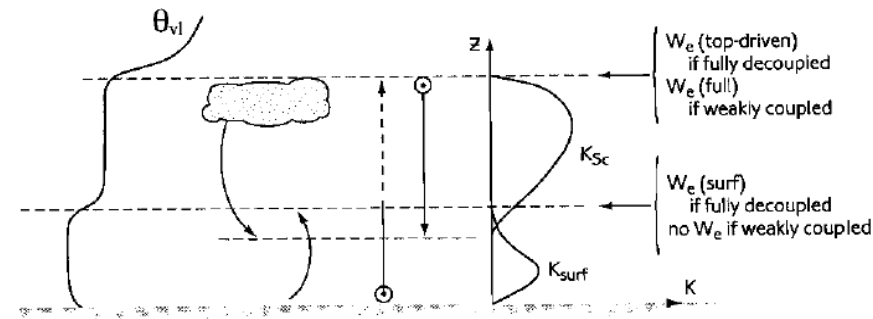
(c)

III. Single mixed layer, possibly cloud-topped
(no cumulus, no decoupled Sc, unstable surface layer)



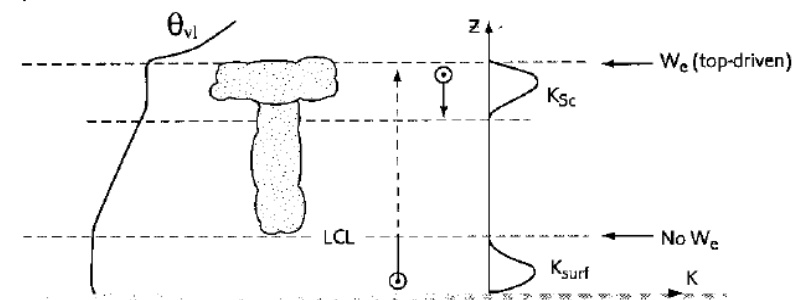
(d)

IV. Decoupled stratocumulus not over cumulus
(no cumulus, decoupled Sc, unstable surface layer)



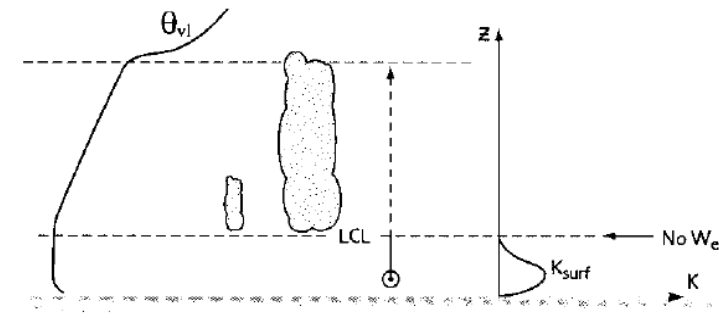
(e)

V. Decoupled stratocumulus over cumulus
(cumulus, decoupled Sc, unstable surface layer)



(f)

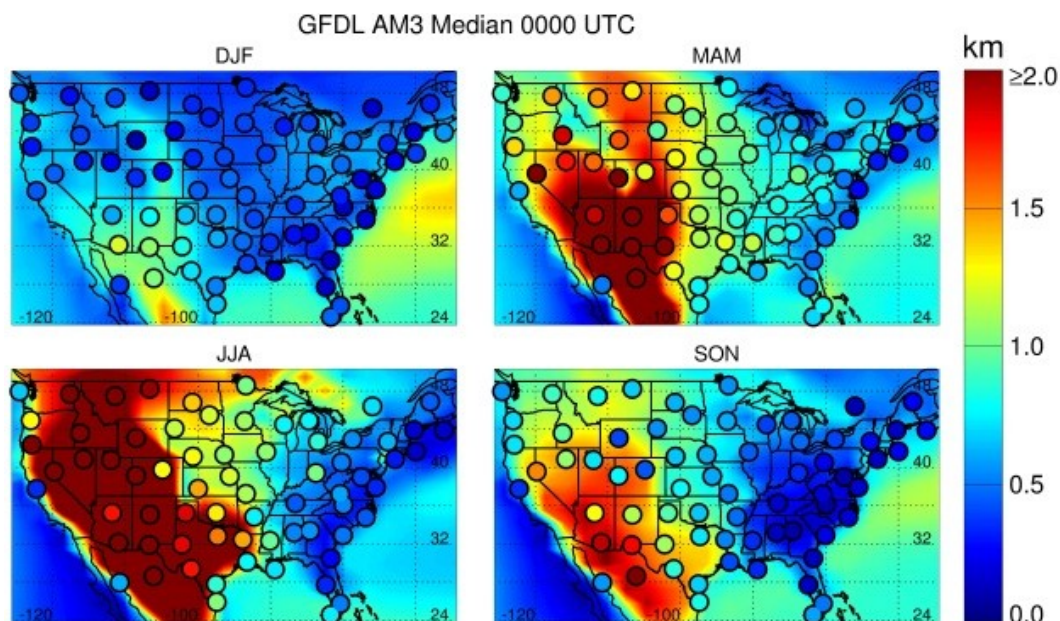
VI. Cumulus-capped layer
(cumulus, no decoupled Sc, unstable surface layer)



Evaluation of PBL median height: radiosondes and GFDL AM3

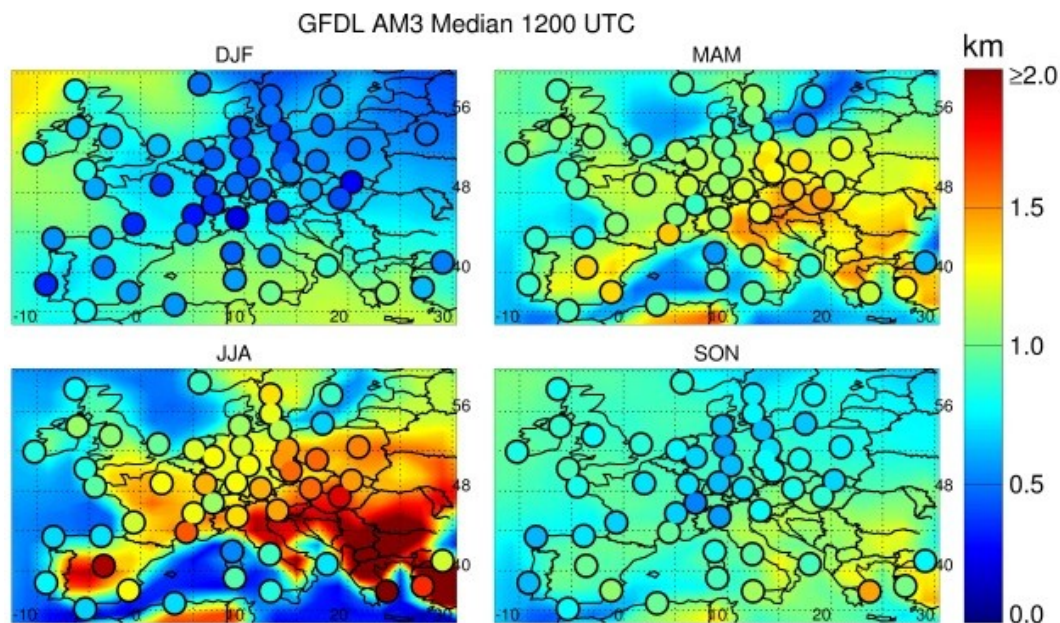
Seidel et al. (2012, JGR, in press)

PBL height computed consistently
between radiosondes and model



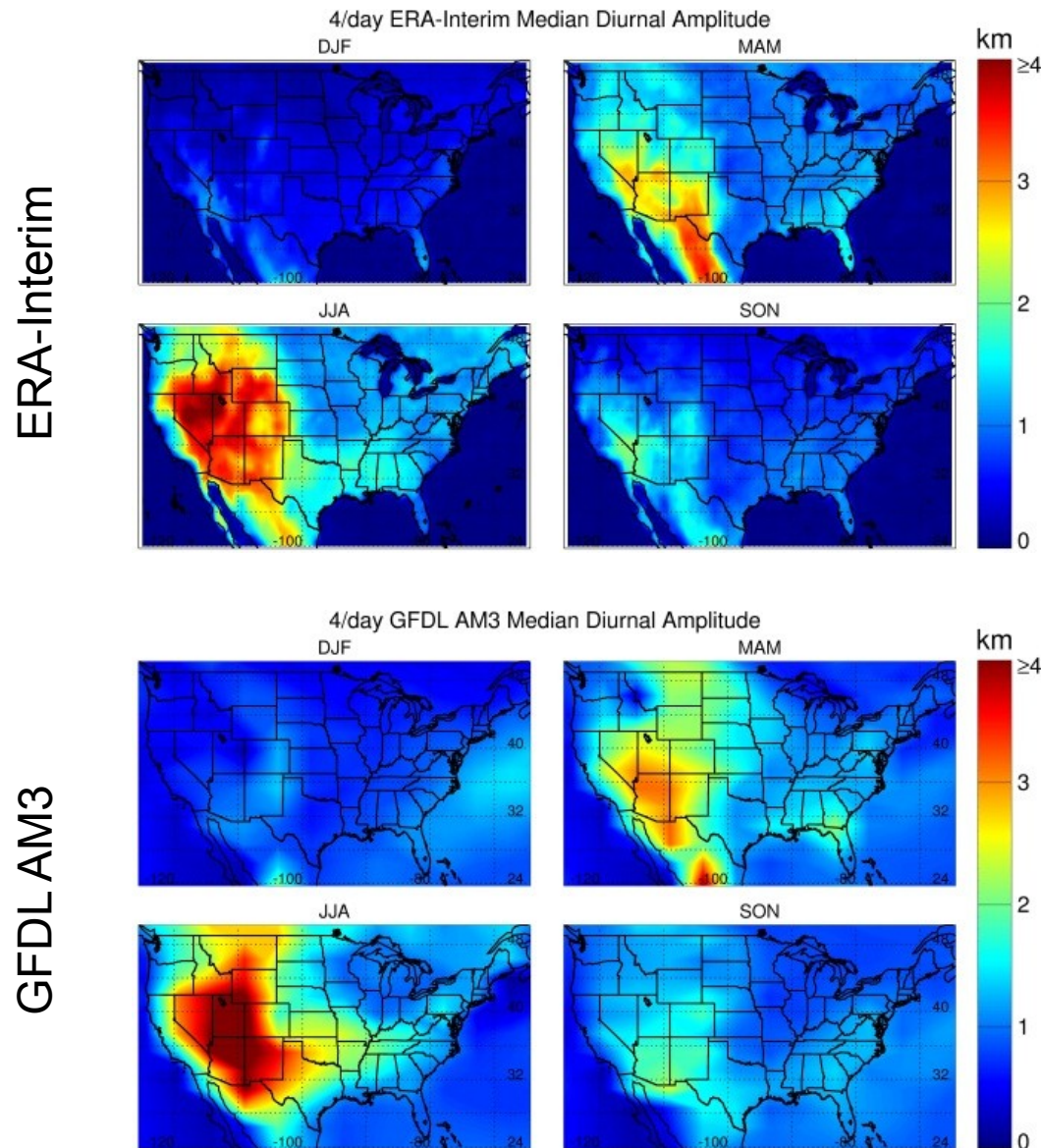
Continental US 0000 UTC
~ evening

Europe 1200 UTC
~ mid-day



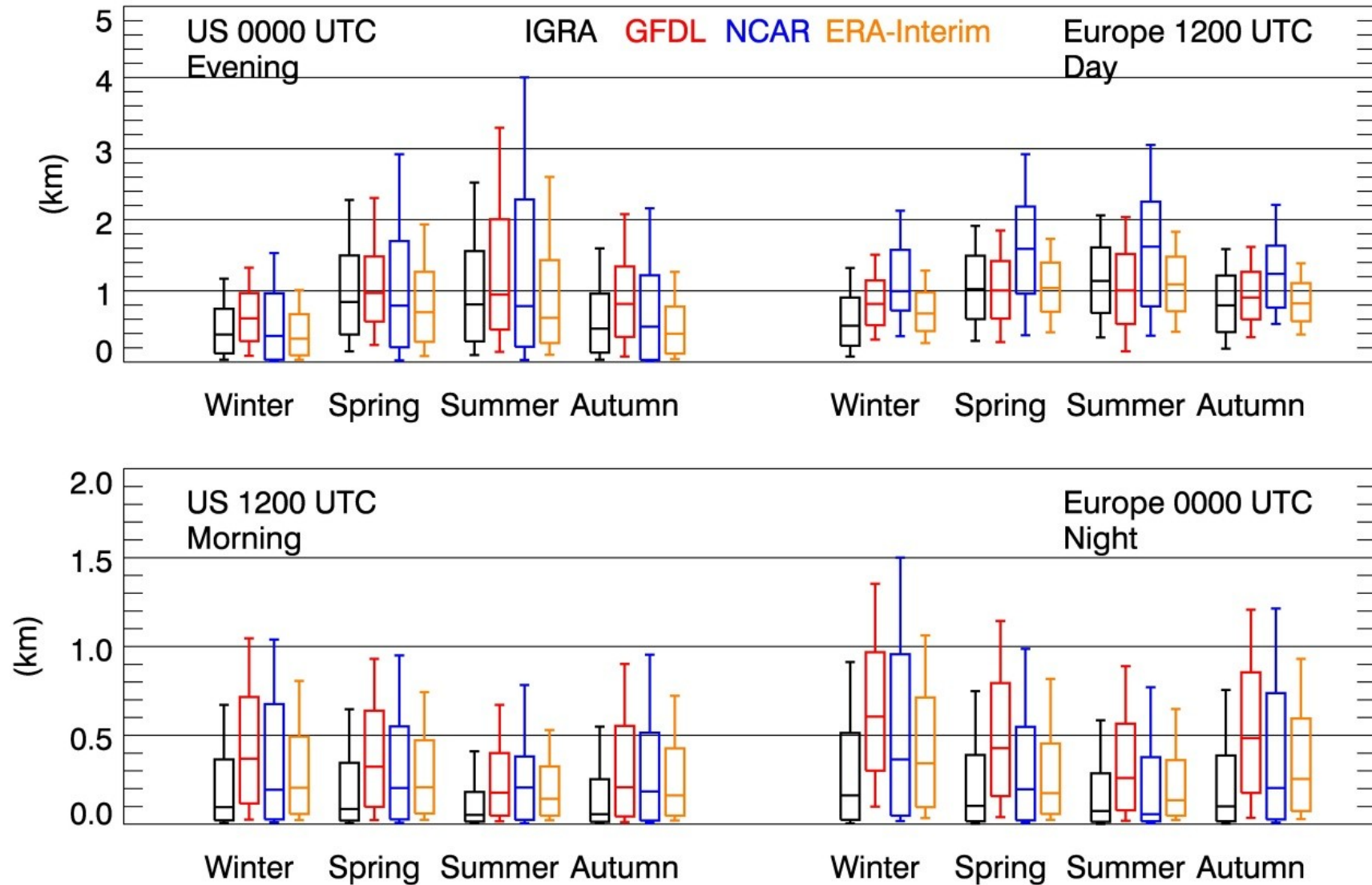
PBL diurnal amplitude: GFDL AM3 vs ERA-Interim

Seidel et al. (2012, JGR, in press)



PBL height distribution

Radiosondes (IGRA), GFDL AM3, NCAR CAM5, ERA-Interim



Seidel et al. (2012, JGR, in press)

Clouds in GCMs

- GCMs typically distinguish between two types of clouds and precipitation
 - large-scale,
 - convective
- In AM3, convective clouds are further decomposed into
 - shallow convection,
 - deep convection.

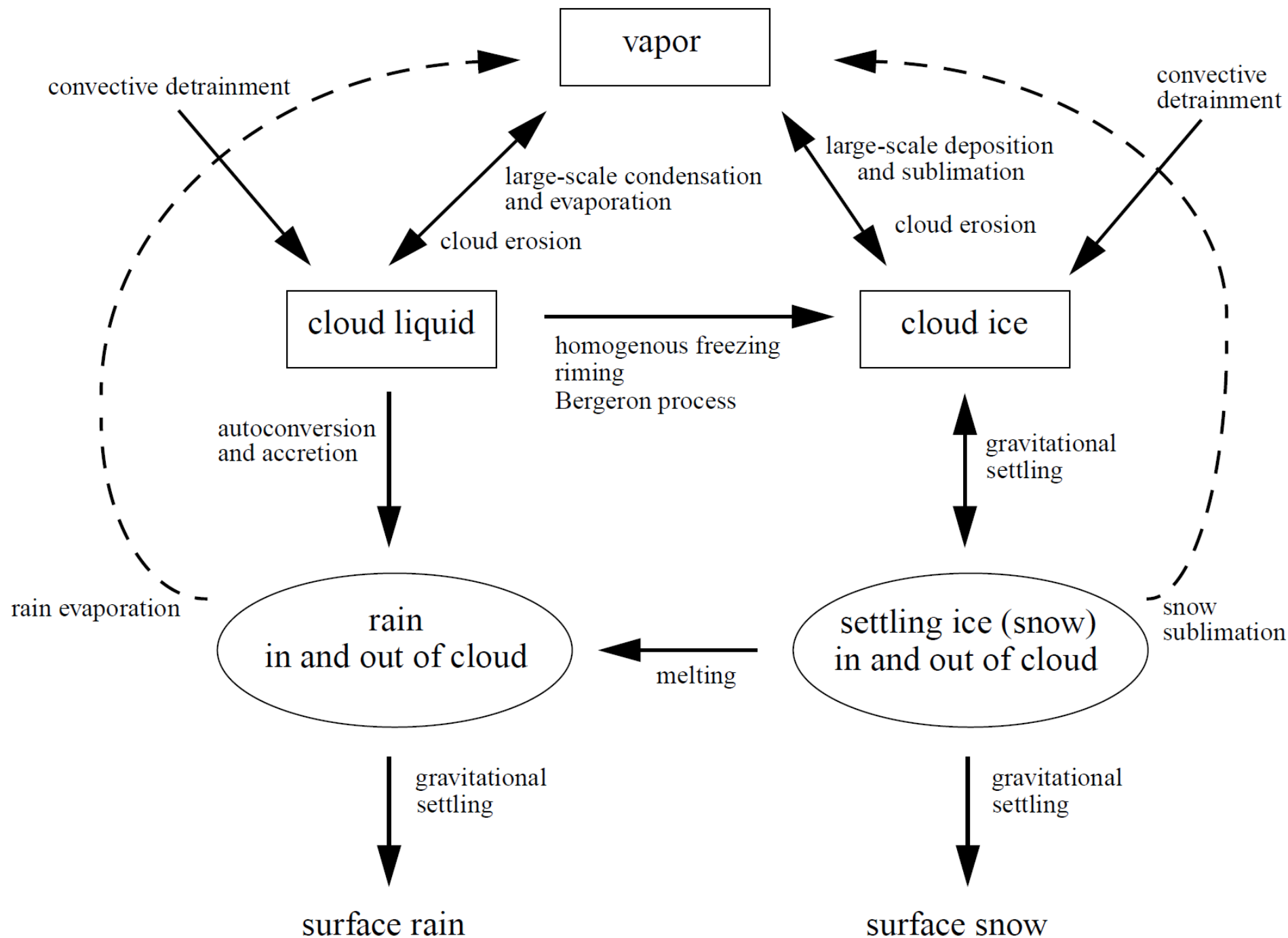
AM3 large-scale clouds

- AM3 includes **prognostic** equations for
 - cloud fraction, q_a
 - cloud liquid mass, q_l
 - cloud liquid number, q_n
 - cloud ice mass, q_i
- Ice number is **diagnostic**
- Precipitation is **diagnostic** (rain, snow).

Macro and micro-physics

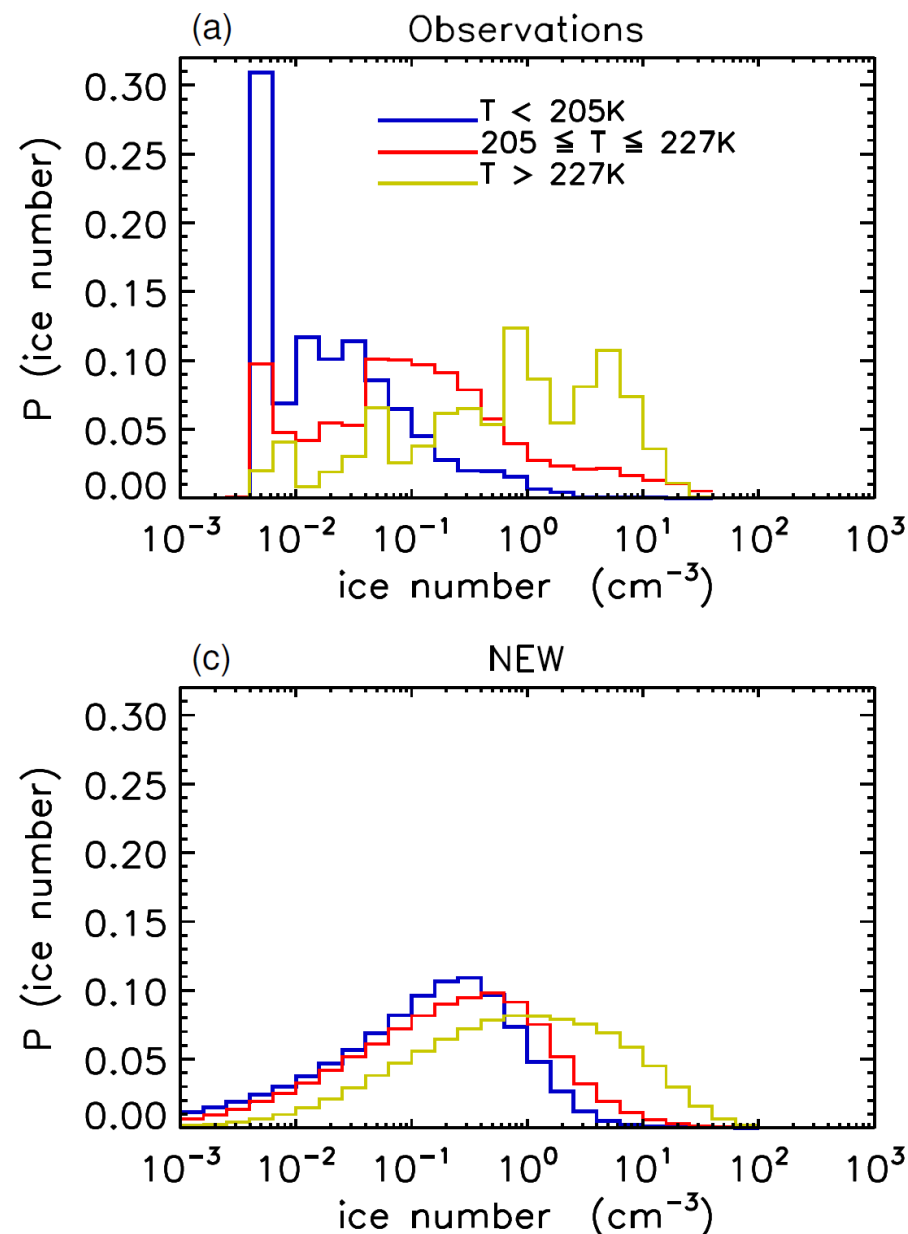
The AM3 large-scale cloud scheme can conceptually be decomposed into

- Macro-physics
 - Prediction of cloud fraction
 - Large-scale condensation, evaporation
 - Based on Tiedtke (1993, MWR)
- Micro-physics
 - Conversion of cloud liquid/ice to precipitation
 - Precipitation in clear/cloudy regions
 - Based on Rotstayn (1997, QJRMS), Jakob and Klein (2000, QJRMS).
 - Prognostic cloud drop number by Ming et al. (2006, JAS).



Two-moment microphysics option

- AM3 also includes an option to use a full two-moment microphysics (Salzmann et al. 2010, ACP)
- **Prognostic ice number** concentration linked to aerosols.



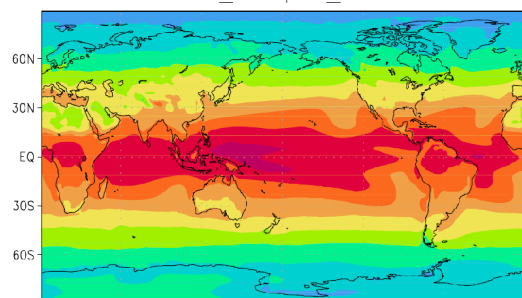
Cloud tuning

- GCMs are “tuned” to achieve the proper radiative balance:
 - Net TOA radiation: $0.5 - 1.5 \text{ W/m}^2$
 - TOA SW absorbed and OLR between 235 and 245 W/m^2 .
- Tuning is often accomplished by adjusting parameters in the cloud schemes.

AM3 top of the atmosphere radiation: 1981-2010

ANN NETRADTOA (W/m^2)

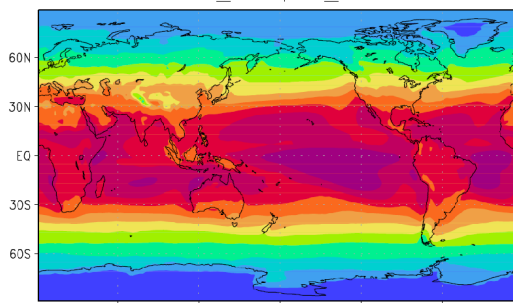
c48L48_am3p10_2thread



Mod = 1.26052 (model grid) SDev = 58.2299

ANN SWABS (W/m^2)

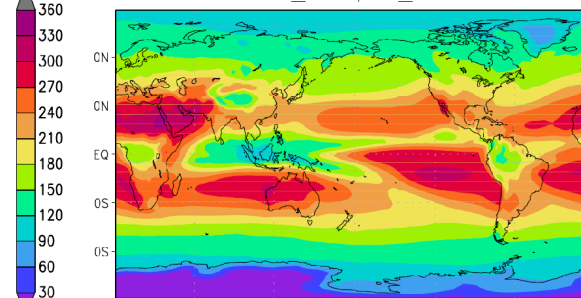
c48L48_cm3p10_2threcd



Mod = 236.692 (model grid) SDev = 79.8123

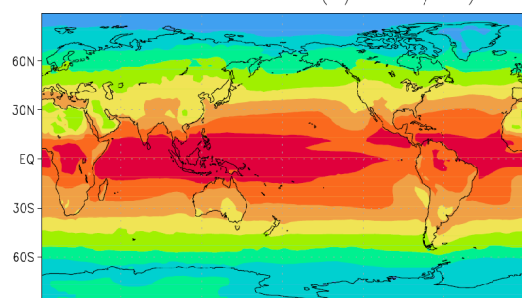
ANN OLR (W/m^2)

c48L48_am3p10_2threcd



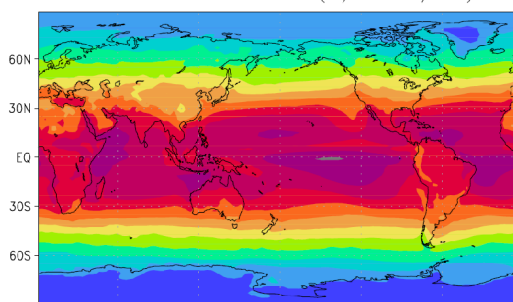
Mod = 235.431 (model grid) SDev = 30.3445

CERES EBAF Ed2.6 (3/00-2/10)



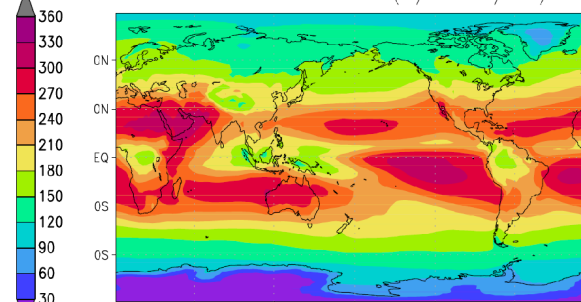
Obs = 0.510541 (regrid to model grid) SDev = 56.1414

CERES EBAF Ed2.6 (3/00-2/10)



Obs = 240.276 (regrid to model grid) SDev = 80.1286

CERES EBAF Ed2.6 (3/00-2/10)



Obs = 239.766 (regrid to model grid) SDev = 29.7361

	Net	SWABS	OLR
AM3	1.26	236.7	235.4
CERES	0.51	240.3	239.8

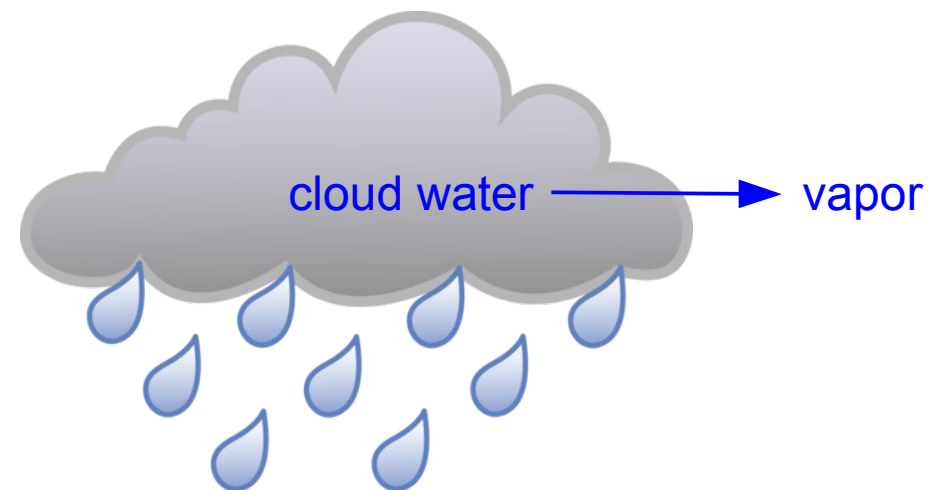
Cloud tuning

- **Erosion scales:** control horizontal mixing between clouds and the environment
- Units: $1/s$ (inverse time scale)
- Base value, plus separate values when convection or turbulence is active.
- AM3 values

```
strat_cloud_nml:
```

```
eros_scale = 1.3e-6,  
eros_scale_c = 7.e-5,  
eros_scale_t = 7.e-5,
```

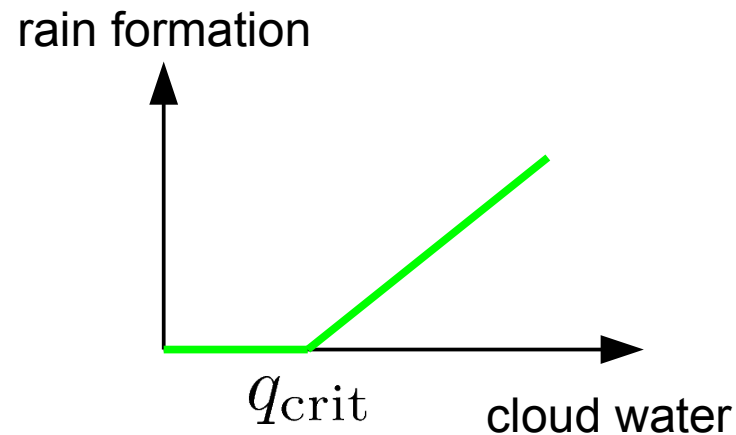
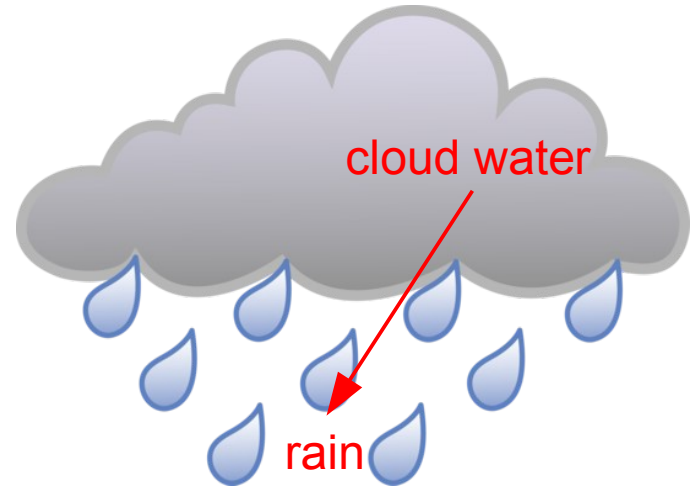
- Original Tiedtke (1993) value:
 $1.0e-6 \text{ s}^{-1}$



Cloud tuning

- **Auto-conversion** threshold for the onset of precipitation formation.
- Units: μm

```
strat_cloud_nml:  
    rthresh = 8.2,
```
- Range of GFDL models: 6.0 to 10.6



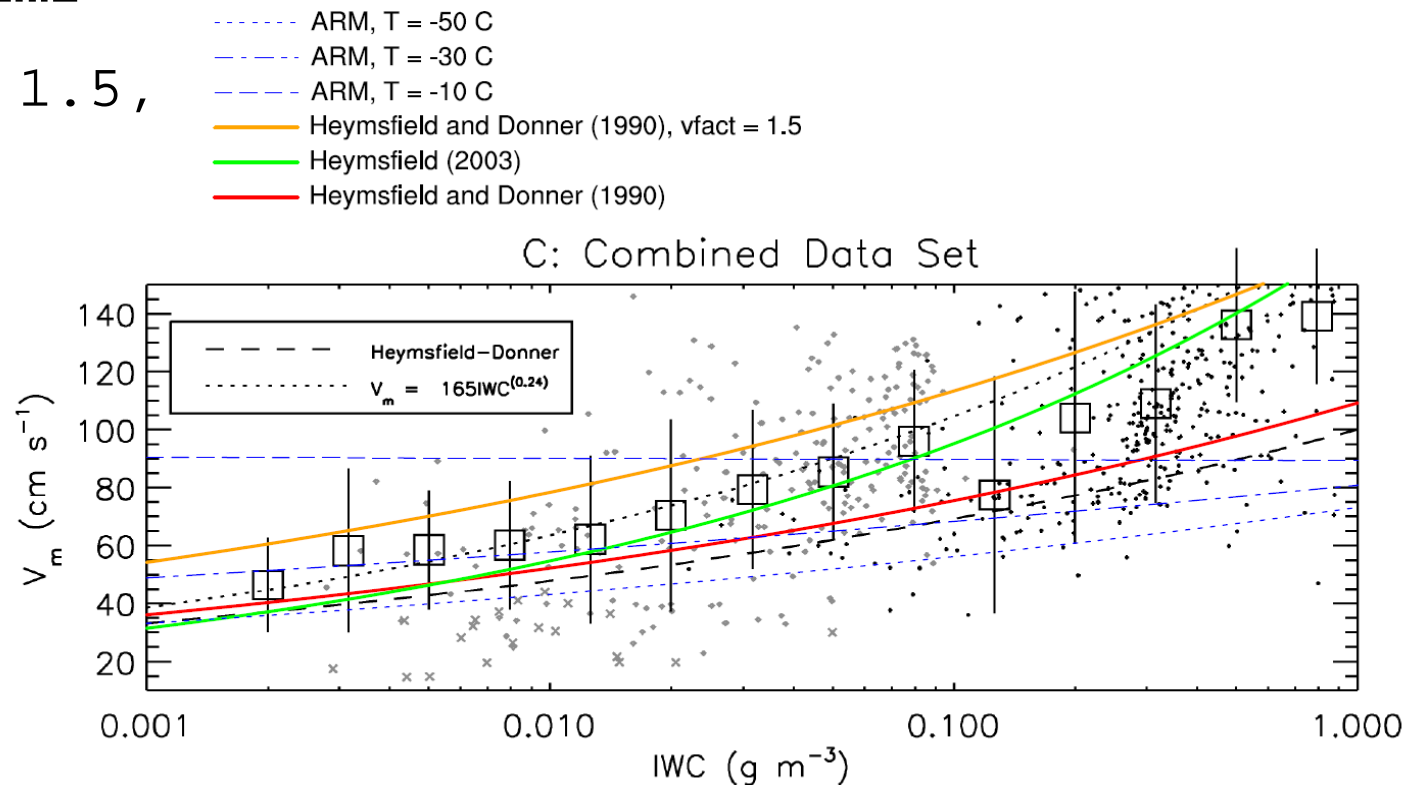
$$q_{\text{crit}} = \frac{4}{3}\pi \frac{\rho_l}{\rho} r_{\text{thresh}}^3 N$$

Cloud tuning

- **Ice fall velocity**
- Factor scaling ice sedimentation velocity

strat_cloud_nml:

vfact = 1.5,



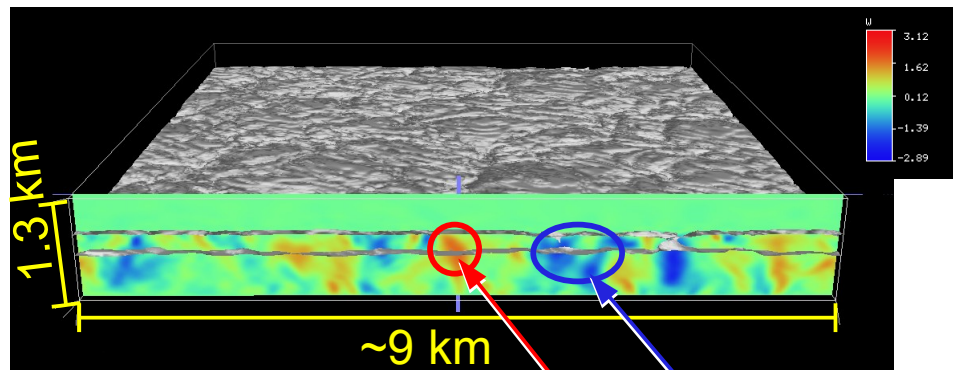
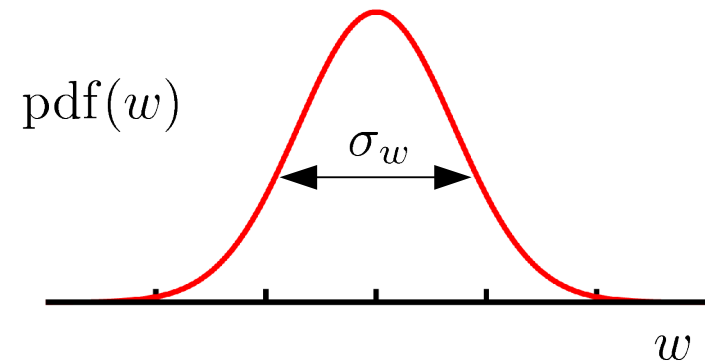
Background figure: observations and fit from Heymsfield (2003, figure 11c). Color overlay: Heymsfield and Donner (1990) fit (red); Heymsfield (2003) fit (green); Heymsfield and Donner (1990) fit with vfact = 1.5 (gold); ARM data derived fit at various temperatures (blue; Deng and Mace 2008).

Cloud tuning

- **Minimum vertical velocity variance** for cloud drop activation σ_w
- Units: m/s

```
strat_cloud_nml:  
    var_limit = 0.7
```

$$\overline{N^*} = \int N^*(a_1, \dots, a_n, T, p, w) \text{pdf}(w) dw$$



LES of GCSS DYCOMS-II RF01

Updraft:
activation

Downdraft:
evaporation

Cloud tuning

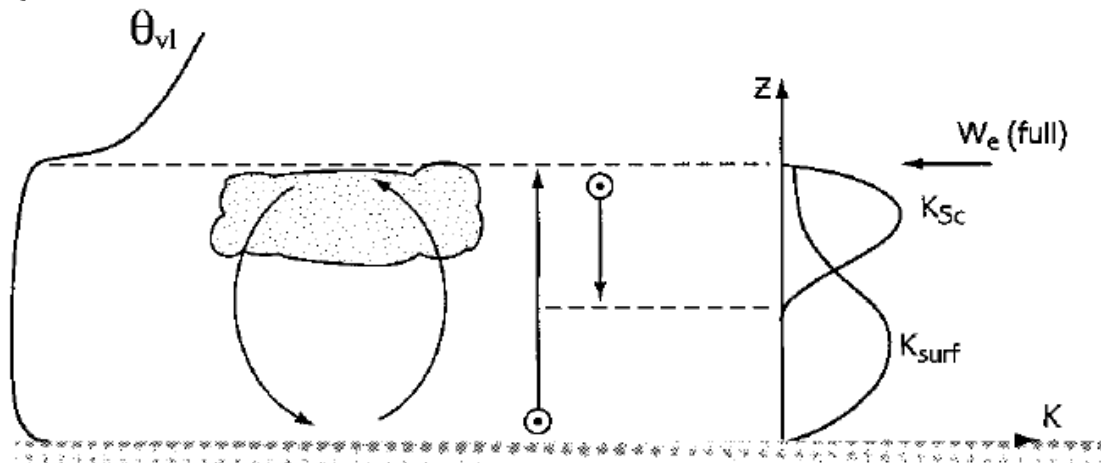
- Cloud top entrainment in PBL scheme

`&entrain_nml`

`beta_rad = 0.5,`

- Default value from Lock et al. (2000): 0.23

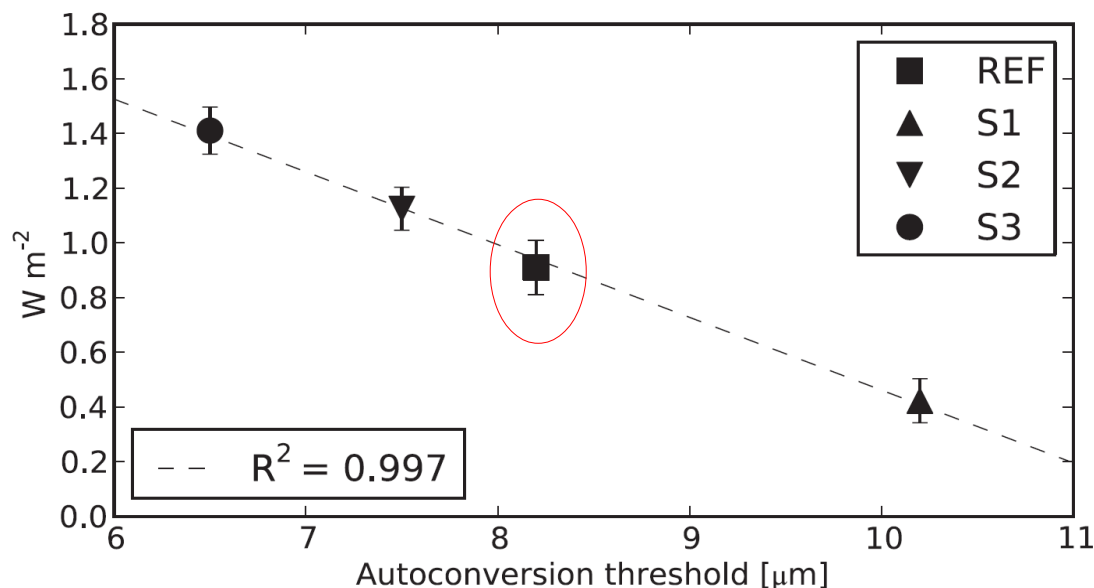
III. Single mixed layer, possibly cloud-topped
(no cumulus, no decoupled Sc, unstable surface layer)



$$w_e = A_1 \frac{V_{\text{sum}}^3 / z_{\text{ml}} + g \tilde{\beta}_T \alpha_t \Delta_F}{\Delta b + c_T V_{\text{sum}}^2 / z_{\text{ml}}},$$

Tuning is not always benign...

Radiative flux perturbation



Magnitude of aerosol indirect effect can change by $\pm 0.5 W/m^2$ by changing r_{thresh}

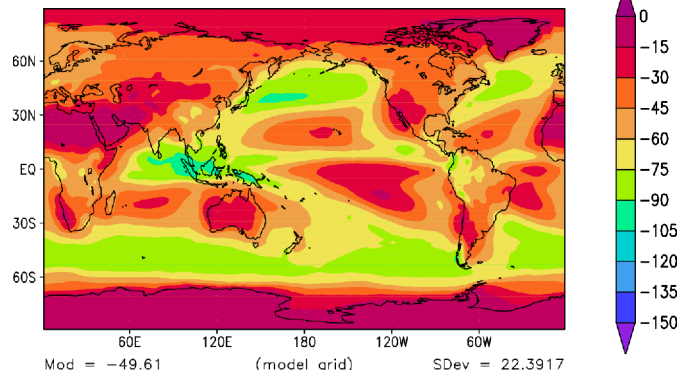
Golaz et al. (2011, J Clim)

	Radiative impact (W/m^2)
Greenhouse gases	+ (warming)
Aerosol direct effect	≈ 0 in AM3/CM3
Aerosol cloud indirect effects	- (cooling)
Net Radiative Flux Perturbation (RFP)	+0.91

Cloud forcing

ANN SWCF (W/m^2)

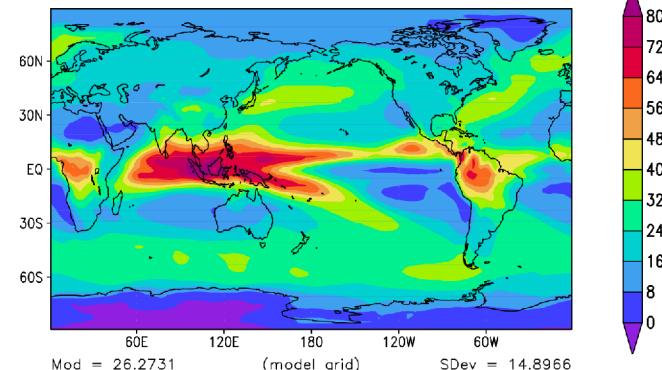
c48L48_am3p10_2thread



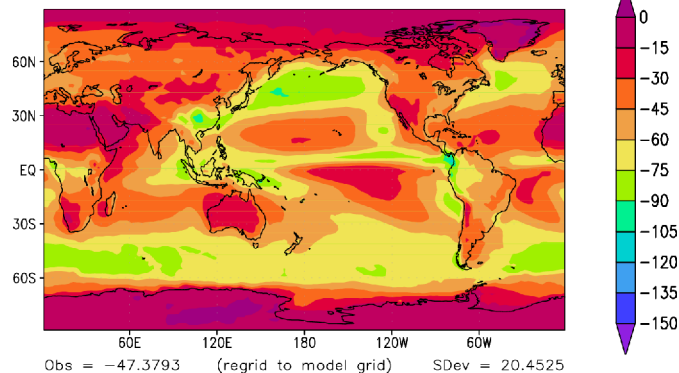
AM3

ANN LWCF (W/m^2)

c48L48_am3p10_2thread

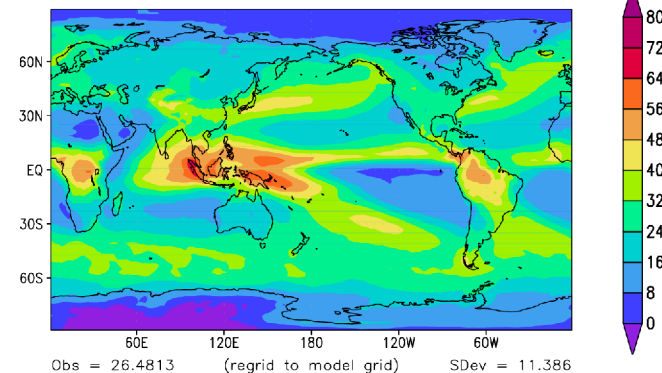


CERES EBAF Ed2.6 (3/00-2/10)

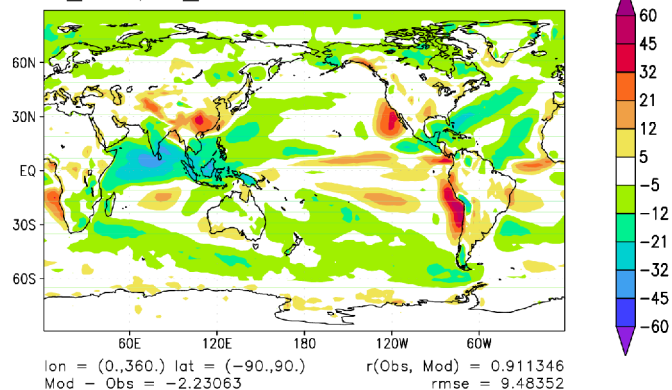


Observations
CERES-EBAF

CERES EBAF Ed2.6 (3/00-2/10)

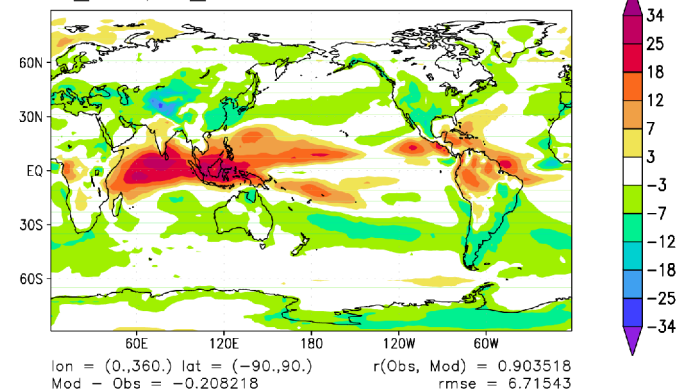


c48L48_am3p10_2thread minus CERES EBAF Ed2.6



Difference

c48L48_am3p10_2thread minus CERES EBAF Ed2.6



CERES EBAF Terra Edition2.6:

<http://ceres.larc.nasa.gov/products.php?product=EBAF>
Loeb et al. (2009), J. Climate

CERES EBAF Terra Edition2.6:

<http://ceres.larc.nasa.gov/products.php?product=EBAF>
Loeb et al. (2009), J. Climate

Precipitation partitioning (1981-2010)

c48L48_am3p10_2thread

